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AFTER SITGES

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Introduction

This talk is not meant as a summary of the many contributions to this workshop but I would rather like to pick up a few key issues which will drive our future work.

For the physics issues, one may distinguish them according to the 2 stages in energy which are foreseen for the next linear collider.

Below a centre of mass energy of 500 GeV, one would cover the light Higgs scenario, top physics at threshold (widely studied at previous workshops) and eventually take data at the Z pole. The later idea, first proposed by the JLC community, seems a logical step given the high accuracy which would be achievable on electro-weak measurements with a LC operating at high luminosity with longitudinal polarisation. These accuracies would match the precisions which can be obtained for the top and the Higgs mass, at the level of ~ 100 MeV, with however a remaining problem due to the present uncertainty on $\alpha(M_Z)$.

Above a centre of mass energy of 500 GeV, one would cover the realm of SUSY, compositeness (non elementary Higgs scenario, e.g. the technicolor scenario TC) and indirect searches for Z' , new dimensions, anomalous couplings through precision measurements on fermion pairs and W pairs. Except for the CLIC scheme (not studied during this workshop), none of the 3 schemes presented so far has the potential to go above 1 TeV.

A key issue, which to my mind has not received sufficient attention so far, is to compare systematically the measurement/discovery potential of a LC to LHC. This comparison has been initiated in the past and I will recall some relevant results. These comparisons should be updated taking into account recent studies achieved within the 2 communities.

Detector issues will be discussed with attention given to the "Large-Small" debate triggered by the NLC community. Physics issues are guiding our choices while machine backgrounds and constraints constitute our main limitations.

The light Higgs scenario

1/ Prospects for a light Higgs

Precision measurements are consistent with a contribution of a light Higgs[1]:

$$\text{Log}_{10} m_H^{GeV} = 1.85^{+0.31}_{-0.39}$$

This result is however not a proof of existence of the Higgs boson. Alternatively if there is no Higgs, the SM is non-renormalisable and one may reinterpret this contribution as $\text{Log}_{10} \Lambda_{NEW}$ where Λ_{NEW} is related to the scale of new physics which provides an adequate U.V. cutoff[2]. One can therefore conclude optimistically that some kind of new physics should appear at a scale well within the LC energy scale.

Table 1: Expected accuracies on Higgs branching ratios

$b\bar{b}$	$c\bar{c}$	gg	WW*	$\tau^+\tau^-$	Inv
2%	8%	6%	2-10%	6%	?

The standard model interpretation gives, at 95% C.L:

$$95 < m_H < 230 \text{ GeV}$$

while the central value ~ 100 GeV is consistent with the MSSM prediction[3].

One should underline once more that a light Higgs scenario appears as an inescapable prediction of SUSY at low energy scale even within non MSSM schemes where there could be substantial reduction of the production cross-section and/or detection problems (e.g. invisible decays). The final word on this theory (the "SUSY killer") therefore requires[4] a LC operating at centre of mass energies up to 500 GeV.

Alternate schemes are not favoured.

The strongly interacting electro-weak scheme would fake a large effective Higgs mass. One can however conceive that some new physics contribution produces an appropriate cancellation.

The Technicolor scheme, TC, is excluded in its minimal version which mimics the QCD behaviour, since it would give[5] $S > 0.25$. Precision measurements (assuming a large "Higgs" mass which is appropriate within TC) give $S = -0.27 \pm 0.12$. In extended versions[6], "walking technicolor", S cannot be computed anymore but the theory predicts light technirhos decaying into technipions which could be found at a LC with clean signatures[7] ($b\bar{b}$, $b\bar{c}$, $\tau\nu\dots$).

2/ Branching ratios, total width and mass measurements

If one can assume a vertex detector starting at a radius of ~ 1 cm (see section on detector issues), the Higgs boson decay modes can be measured with excellent purity/efficiency. In table 1 are indicated the accuracies which could be reached taking an integrated luminosity of 500 fb^{-1} , at $\sqrt{s} = 350$ GeV, which corresponds to the TESLA scheme. Figure 1 gives the expected variation[8] of these accuracies with the Higgs mass. The most challenging mode is clearly $c\bar{c}$ since it requires separation from the dominant $b\bar{b}$ mode. The separation from the gluon-gluon, gg, channel is also needed since this mode suffers from large theoretical uncertainties[9].

At this level of experimental accuracy, one needs a special effort to reduce these uncertainties on $c\bar{c}$ (the running charm mass) and gg (this mode is of interest within SUSY since it can be influenced by loop contributions from the stop sector).

It is fair to say that for the $\tau^+\tau^-$ channel full use of the high accuracy VD has not been achieved and therefore further improvements are expected. The

invisible mode has not yet been investigated but, judging from LEP2 results, it should also lead to excellent results.

The branching ratio into WW^* becomes measurable if $m_h > 100$ GeV. Detailed analyses, in progress[10], indicate that this measurement can be very precise (the range given in table 1 corresponds to a mass interval 110-130 GeV for m_h). This mode can be used to discriminate between SM and MSSM since the ratios $b\bar{b}/WW^*$ and $\tau^+\tau^-/WW^*$ depart significantly from SM if $m_A < 1$ TeV. In MSSM the deviation comes from the $b\bar{b}$ and $\tau^+\tau^-$ partial widths with almost no effect on WW^* . One can verify this assumption using the Higgstrahlung and fusion processes. For instance $\sigma(hZ)$ can be measured with an accuracy of $\sim 2\%$. This test would already seem sufficient to most theorists but one can also check the h-W-W coupling using the fusion process to be complete (there is not yet an estimate on the accuracy which can be reached on this process).

If we can measure $BR(h \rightarrow WW^*)$ and control h-V-V, it becomes possible to derive the total width Γ_T^h through the trivial formula:

$$\Gamma_T^h = \Gamma_{SM}(h \rightarrow WW^*)/BR(h \rightarrow WW^*)$$

where I have assumed that h-V-V was found standard. If not, $\Gamma_{SM}(h \rightarrow WW^*)$ should be replaced by $\Gamma_{SM}(h \rightarrow WW^*)\sigma(hZ)/\sigma_{SM}(hZ)$. The precision on Γ_T^h follows directly from that on $BR(h \rightarrow WW^*)$. This level of accuracy, in the mass domain corresponding to MSSM, cannot be achieved with a hadron collider.

The Higgs mass can be determined to better than 100 MeV using the leptonic decays alone and one sees no reason which would prevent using as well hadronic decays. An accuracy at the level or better than 50 MeV seems therefore feasible.

This brief panorama of the potential of a LC for what concerns a precise determination of the Higgs properties (mass, cross-section, branching ratios, total width) illustrates convincingly that a LC can provide unique opportunities for this type of physics.

The high luminosity option is necessary to reach the sensitivity needed to distinguish between SM and MSSM in a domain of parameters which is beyond LHC and LC discovery reach (see figure 2). It seems reasonable to assume that TESLA operating at full luminosity for 2 years with an effective integrated time of $\sim 10^7$ sec/year could collect 500 fb^{-1} at \sqrt{s} .

3/ Challenging channels

The measurement[12] of $BR(h \rightarrow 2\gamma)$ is severely limited by radiative backgrounds and would give a poor accuracy, $\sim 20\%$, even requiring integrated luminosities well above 500 fb^{-1} . An alternate method would be to use a $\gamma - \gamma$ collider which would directly give $\Gamma(h \rightarrow 2\gamma)$ with an estimated precision $\sim 3\%$ [13]. The total width, obtained combining the 2 measurements, would therefore also be known at the $\sim 20\%$ level.

The process Zh^* , with $h^* \rightarrow 2h$, would give a direct determination of λ , the coefficient of the quartic term in the Higgs potential ($V(\Phi) = \mu^2\Phi^2 + \lambda\Phi^4$). At

$\sqrt{s}=500$ GeV, one has typically $\sigma(\text{Zhh})\sim 0.3$ fb. With an integrated luminosity of 2 ab^{-1} , one could measure λ at the $\sim 15\%$ level[14]. It is fair to say, however, that present analyses are not yet optimised and therefore there is room for progress (or reduction on the amount of luminosity needed to achieve this precision). This measurement gives a fundamental piece of information on the Higgs potential but how precisely do we need such an information to be sensitive to non-standard effects ? This question has not, to my knowledge, received a satisfactory answer.

A similar challenge resides in the measurement of the top-Higgs Yukawa coupling[15] which can be measured from the $t\bar{t}h$ final state. This cross-section is at the fb level and first estimates are giving a $\sim 10\%$ error on the Higgs Yukawa coupling.

Above channels are clearly at the border of what can be achieved and put severe demands on the quality of the detector (energy resolution on photons, multi-jet analysis).

Physics at $\sqrt{s} > 500$ GeV

A question naturally arises: can we set a scale on \sqrt{s} for discovering (directly or indirectly) physics beyond the SM ? So far we can only gather negative informations:

- No significant deviation from SM has been observed so far (if one excepts the super-K results)
- The value of S indicates that we cannot hope for new heavy doublets
- $M_{Z'} > 600$ GeV from the TEVATRON (this limit will rise to ~ 1 TeV with the upgrade) and similar limits from LEP2.

Supersymmetry appears as the most likely scenario, at least judging from the amount of interest given to this topic in our community. Unfortunately there is no clear prediction for the relevant mass scale:

- GUT or "naturalness" arguments are too vague since they state that $M_{SUSY} < 1-10$ TeV

- Requesting that a LC has the same discovery reach as LHC leads to $\sqrt{s} > 1.5$ TeV (see figure 3) baring in mind that for these large SUSY scales not covered by a LC at 1 TeV, LHC will need large integrated luminosities and will only perform an "inclusive discovery" on the basis of missing transverse energy not being able to make very significant measurements

- This criterion is clearly not true for the chargino-neutralino sector for which a LC with $\sqrt{s} = 500$ GeV already covers (see figure 4) a larger energy domain than LHC (at LHC heavy charginos are only produced through cascades from squarks or gauginos which mean that their observation is more model dependent)

- Fine-tuning arguments[16] are clearly requesting light charginos with the usual ambiguity on the definition of F.T. (10% means masses below 90 GeV,

1% means below 300 GeV)

- EW baryogenesis[17] calls for a light Higgs and a light stop (LEP2 should cover this scenario).

In summary, no safe estimate can be made on the minimal energy required for discoveries. One should however remember that our main concern remains EWSB which, as discussed in previous section, implies that new physics should manifest itself at low scale unless some malicious cancellation is faking a light Higgs behaviour. If there is no light Higgs one can expect that strong interactions will be observable within the gauge boson sector. This type of scenario will obviously require the highest possible energy (see discussion in section on precision measurements).

SUSY

We do not have a SM for SUSY but various schemes which are more or less consistent with the constraints imposed by the flavour sector (FCNC), fine-tuning, electro-weak symmetry breaking, cosmology:

- mSUGRA[18] assumes mass unification for gauginos $M_i=M_{1/2}$, and scalars, m_0 , at GUT scale while μ , the Higgsino parameter, is usually related to these masses using the EWSB constraint. The LSP is a stable neutralino (R-parity conservation), a natural candidate for dark matter provided that both m_0 and $M_{1/2}$ are not too large (therefore within the LC reach) as shown in figure 3.

- GMSB[19] has the same unification assumptions for masses but the LSP is a very light gravitino

- Unification of masses at GUT is not mandatory within "string inspired" models and one may well have unexpected scenarios[20] (LSP=gluino if $M_3 < M_{1,2}$, mass degeneracy between the lightest neutralino and the lightest chargino ($M_1=M_2$ at our scale) resulting in problematic detections)

- Higher dimensions, at the TeV^{-1} scale, provide a SUSY breaking mechanism which could be compatible with very heavy SUSY particles[21] (up to 10 TeV !) with no clear dark matter candidate

- etc...

R-parity violation could be present, providing a mechanism for the super-K effect, CP violation[22], i.e. mass terms with phases, is possible and even desirable in view of baryogenesis.

This brief digest shows that a SUSY scenario could be rather complicated and therefore requires the powerful tools provided by a LC: well defined energy with polarised beams and clean environment (detector and physics backgrounds). In a mSUGRA scenario μ , M_1 and M_2 can be measured independently from the neutralino/chargino channels with precisions typically 10 times better[23] than at LHC. If m_0 is small enough, a LC allows for very elegant spin-parity measurements (A_{FB}, A_{LR}) which provide detailed informations: production mechanisms, mass universality in the slepton sector, $\tan\beta$ etc...

It is worth noting that there will be more observables than mass parameters and therefore one could be sensitive to the presence of phases. This has been known for some time[24] but has not yet been explored quantitatively by experimentalists: an urgent job to be done !

As mentioned previously, life may be very hard if there are degenerate scenarios, e.g. chargino or stop degenerate in mass with the lightest neutralino. As pointed out[25] a LC allows to cope with these situations and such techniques have already been used at LEP2[26](see also the discussion for the Tevatron[27]).

The GMSB scenario predicts signatures which require specific features from the detector:

- A semi-stable neutralino decaying into photon+gravitino which can be identified as a non-pointing photon with an electro-magnetic calorimeter segmented longitudinally
- A semi-stable slepton decaying into lepton+gravitino which can be identified from the dE/dx information if the tracking device is gaseous (TPC, drift chamber).

These searches are already performed with LEP detectors.

Additional Higgs bosons H , A , H^\pm appearing within MSSM and GMSB are predicted heavy within mSUGRA and therefore not necessarily observable at a LC. A significant gain in mass range could be achieved by running with a photon-photon collider where single production of neutral Higgs bosons allows to reach masses up to $0.8\sqrt{s}$. Up to now this prospect was not credible given the low cross-section for this process and the large background expected. Recently, it was realised that if A and H have masses close enough, interference[13] could substantially increase the yield and also allow to observe an interesting pattern.

In summary a TeV LC has less discovery range than LHC but leaves no blind regions and gives much more precise and less model dependent measurements. A detailed comparison with similar analyses for LHC will help in assessing these statements.

Precision Measurements

A future LC will be able to collect very large samples of data and therefore the dominant errors will come from systematics. A lot will therefore depend on our ability to measure the differential luminosity $d\mathcal{L}/d\sqrt{s}$ (to better than 1% is hoped for) and determine precisely the longitudinal polarisation. The latter aspect, as recognised by the experts, has so far received little attention.

The classical menu relies on $f\bar{f}$ and WW final states.

$$1/ f\bar{f}$$

These channels allow to search for various phenomena beyond the SM: Z' , W' (using the $\nu\bar{\nu}$ channel with ISR), Kaluza-Klein excitations, R-parity violation (e.g. s-channel exchange of a virtual sneutrino), leptoquarks (t-channel

exchange), preons etc... Generally speaking one can parametrise these effects in terms of couplings and mass scale and set limits on these[28]. If some significant deviation is observed, one will in general be able to discriminate between these mechanisms by using the large set of precise observables (A_{FB}, A_{LR}, τ and top polarisation) provided by a LC operating with polarised beams.

A LC at \sqrt{s} well below the Z' resonance has a discovery reach which extends for Z' masses up to $\sim 5-10\sqrt{s}$ depending on models. Observables allow to discriminate between these various models and indirectly estimate $M_{Z'}$. On the contrary LHC will be able to provide directly $M_{Z'}$ but has too few observables to discriminate between the various models. Figure 5 gives a summary of the discovery reach of the various machines[29].

A scenario with additional dimensions at a nearby scale has recently received much attention[30]. Schematically, one can distinguish 2 schemes. In practice some models are combining features of these 2 schemes.

In the first scheme one assumes that SM interactions will feel a new dimension at a scale of order TeV^{-1} . Kaluza-Klein towers of known particles (e.g. photon, Z) will appear at that scale and modify $f\bar{f}$ observables.

In a second scheme, only gravity sees the new dimensions at a size R which depends on the number of extra dimensions. At this scale the Planck mass M_{Pl} is replaced by an effective mass M_{eff} taken $\sim 1 \text{ TeV}$ to avoid the hierarchy problem (not below to avoid any conflict with observations). Both masses are related through:

$$M_{Pl}^2 = R^\delta M_{eff}^{2+\delta}$$

where δ stands for the number of extra dimensions and should be above 2 to avoid any conflict with cosmology ($\delta=2$ gives $R \sim 1 \text{ mm}$, acceptable for gravity at short distance, but in apparent conflict with supernova observables[31]).

In this scheme Kaluza-Klein excitations of the graviton G are seen near the M_{eff} scale. One can observe $e^+e^- \rightarrow \gamma G_{KK}$ which would give extra contribution[32] over the genuine $\nu\bar{\nu}\gamma$ background. In passing one can note that this signal and the SM background have very similar behaviour in angle and in energy. The sensitivity for this channel will therefore depend on our ability to modelise this background (generators) and our control of the luminosity. This measurement also requires an efficient coverage of the forward region where most of the signal will be collected and a veto on forward electrons down to the smallest possible angles to remove photons due to Bhabha scattering. Studies are under progress[33] but one can estimate that these improvement can gain us significant sensitivity and allow to reach limits on M_{eff} at the level of 10 TeV for $\delta=2$ and lower levels for a larger number of dimensions.

Kaluza-Klein excitations of the graviton will also contribute in standard processes giving more model dependent mass limits (with however less dependence on δ). The spin 2 of the graviton will reflect on angular dependences. Recently[34] important constraints have been set using the electro-weak precision observables.

At LHC the process $gq \rightarrow qG_{KK}$ will dominate the "monojet" contribution. The sensitivity of LHC will depend on systematics (modelling of mono-jets, calorimetry resolution). It will be interesting to compare the reach of each machine for this type of new physics.

2/ WW

This channel provides an ideal laboratory to search for anomalous couplings in the gauge sector. As well known, the sensitivity to anomalies increases dramatically with energy and a gain of 2 orders of magnitude is expected with respect to LEP2 as shown [35] in figure 6.

Deviations should appear in a strong interaction scenario. The largest effect is observed if there is a nearby resonance with $I=1$ which affects the WW channel (note that $I=2$ resonances can be accessed with the e^-e^- scheme) as shown [36] in figure 7. If there is no such resonance, one can in principle measure some effects predicted in the general framework of low energy theorems (see figure 7) but this has to be worked out in detail for $\sqrt{s} = 1$ TeV.

The $WW\nu\bar{\nu}$ channel provides additional informations but seems to give a limited sensitivity for $\sqrt{s} < 1$ TeV. Typically the precision on anomalous couplings improves by an order of magnitude[37] by increasing \sqrt{s} from 0.8 TeV to 1.6 TeV. This conclusion should be investigated in more detail, in particular the tradeoff between energy and luminosity and limitations due to systematics.

Detector issues

This workshop has set very ambitious, but realistic goals for the detector surpassing the LEP/SLD ones. Our aim is to measure precisely photons, electrons, muons and jets over the largest possible solid angle. Perfect efficiency is required meaning that the detector has to provide excellent pattern recognition (3D for tracking, high granularity also in 3D for calorimetry) with the best possible transparency (low X^0). Timing information is also relevant to avoid cumulating mini-jets from different bunches with however widely different constraints between TESLA (300 ns between bunches) and the warm machines (few ns between bunches).

Two philosophies have been considered by the NLC community. The Small detector S has a 6 T field, implying that the electro-magnetic background due to beam-beam interactions is efficiently trapped and that the Si microvertex detector VD can start at $R=1$ cm. A Si tracker is used which guarantees robustness against machine backgrounds. Calorimetry starts at $R=80$ cm implying that one can afford very high granularity and excellent energy resolution for photons (Si+W highly segmented). In this scenario the last focusing Q-pole can remain outside the coil.

Such a scheme has many obvious advantages with some concern however on the possibility of charge/neutral separation which a necessary feature for good

energy reconstruction in a magnetic field.

The Large detector L has a gaseous tracker with a radius $R \sim 2\text{m}$ allowing good separation between charged and neutrals. The gas detector has the advantage of providing high redundancy and allows to measure dE/dx typically with 5% accuracy which can be useful for various analyses. It is more vulnerable to machine backgrounds (e.g. positive ions cumulating inside the sensitive volume of the TPC). The price to pay is of course the large increase of the calorimeter volume which may impose reduced granularity and therefore poor performances on energy flow and on photon measurements (energy and angle).

A compromise seems possible. A micro-vertex starting at a radius of $\sim 1\text{ cm}$ is feasible even with a field of 3 T in the TESLA scheme with appropriate collimation of the beam. One can therefore assume a solenoidal field with very large radius which would include the gas tracker and the calorimeters. Fine-grained calorimetry is considered as a working hypothesis[38] assuming, for the moment $\sim 1\text{cm} \times 1\text{cm} \times 1X^0$ and Si+W. This option may turn out to be totally unrealistic but the proponents of this scheme underline its relevance to reach optimal E-flow performances. Detailed studies are starting for what concerns gas tracker, showing that they can survive in a LC environment with some caution (e.g. using appropriate R.O. schemes for the TPC to avoid positive ion return in the sensitive volume, studying gas mixtures without hydrogen to reduce the effect of slow neutrons). For what concerns the SC Q-pole there does not seem to be any concern for quenches up to a solenoidal field of 4 T. Clearly all these statements have to be well proven by further R&D studies.

Detector \leftrightarrow Physics

Here I will pick up some physics issues which play a critical part in the design optimisation.

1/ Charm tagging

Charm tagging clearly requires a thin VD starting at a radius $\sim 1\text{cm}$. An optimal design should provide $5\text{ }\mu\text{m}$ on the asymptotic precision for the impact parameter and about $5\text{ }\mu\text{m-GeV}$ for the coefficient of the scattering term. This can be contrasted with "ordinary" performances which were taken as $10\text{ }\mu\text{m}$ and $30\text{ }\mu\text{m-GeV}$ respectively. Assuming a charm efficiency at the 50% level, the gain in rejection[39] against beauty is about 4 and the against light quarks of the order of 2.5 as shown in figure 8. This would clearly help in the charm/gluon/beauty separation needed in the light Higgs scenario but not only. Charm tagging will also be an important tool to tag W hadronic decays into $c\bar{s}$ which can be relevant for precision measurements and SUSY analyses (for instance we may want to determine the sign of a W without requesting a semileptonic decay which would reduce kinematical constraints). τ tagging will obviously benefit from this improved resolution but to my knowledge this gain

has not yet been optimally studied.

The choice of technology (CCD, APS, low resistivity Si) will be ultimately determined from a combination of criteria among which radiation hardness (electro-magnetic and neutron backgrounds) which has to include a reasonable safety margin, need for a very thin detector ($\sim 0.1\%$ X^0), lowest possible occupancy (which requires an optimal R.O. scheme). Can we stand 1 hit/mm²/Beam-crossing ? The answer is hopefully yes provided that we use the outside layers of the VD which have a level of background 3 orders of magnitude lower to start a precise tracking and assume that we can extrapolate these tracks to sufficient precision that there are no mis-associations even with such a high occupancy.

2/ Mini-jets

A TPC detector will unavoidably mix interactions occurring in a time slice of order 50 μ s. In the warm scheme this means that the whole bunch train is integrated and that several mini-jets will be superimposed on the event. Very precise timing from an other device is therefore needed if one wants to separate these minijets which occur within ~ 200 ns. In the TESLA scheme there is about 300 ns separation between beam crossing with corresponds to a drift distance of ~ 2 cm, meaning that one can presumably separate geometrically tracks occurring from different beam-crossing. For neutrals accurate timing should be provided by the calorimeter. These aspects, quantified in the JLC studies (possible degradation of Higgs mass reconstruction due to minijets) deserve further investigations.

3/ Calorimetry

E-Flow aspects have been underlined at this workshop with emphasis on the need for calorimeters with good granularity allowing to separate charged and neutrals. One may hope, at best, to achieve a mass resolution of order $30\%/\sqrt{M_{GeV}}$, which would be about twice better than for the ALEPH detector. One may however object that at LEP2 hadronic states are reconstructed using energy-momentum conservation constraints which provide excellent mass resolution, typically at the 2% level, i.e. better or comparable to the best calorimetry that we are discussing. Why should we therefore worry so much to improve on LEP2 performances ? First one can argue that beamstrahlung will degrade the energy-longitudinal momentum constraint, creating tails. Second one can give examples where unconstrained channels (e.g. fusion mechanism with 2 spectator neutrinos) require good mass reconstruction (W/Z separation). Therefore I think that this topic should be given more feedback from physics studies to better assess our need for the "ultimate" E-flow quality which may be at the limit of reasonable cost.

4/ Particle ID

Electron and muon identification is a basic requirement which can easily be achieved for isolated leptons but may be more demanding in complex topologies (6-8 jets) or within jets. A well segmented electro-magnetic calorimeter will be a blessing to identify non isolated electrons. dE/dx information from the gas detector has proven to be a useful tool for medium energy, ~ 5 GeV, electrons.

Search for semi-stable heavy charged sleptons (predicted within GMSB) has been satisfactorily performed at LEP2 using dE/dx information only.

$K-\pi$ separation can be useful to identify charm and beauty. For instance if the VD has found a secondary vertex consistent with the charm hypothesis, we can tell the sign of the D from the kaon sign (if not we need to ask for a semileptonic). If we want to run high statistics at a Z factory, the need for particle identification will be crying...

These arguments, and probably others which have not come to my knowledge, plead for some sort of particle ID. "Poor man's" ID is clearly dE/dx from a gas detector with 5% accuracy to provide a modest $K-\pi$ separation. At LEP, dE/dx information in the ALEPH and DELPHI TPC's was obtained using the wire information which gave important overlap problems (2D information). If we can imagine a full pad R.O. scheme (3D) without losing the gain uniformity and keep the same amount of sampling, one may reach a sufficient dE/dx resolution even within jets.

Cerenkov identification gives clearly a superior $K-\pi$ separation but at the expense of large space losses and, more than anything else, material in front of the electro-magnetic calorimeter. One may argue in favour of a DIRC-type solution, as in Babar, which is sufficiently compact to reduce above problems but this solution only provides $K-\pi$ separation up to ~ 4 GeV.

5/ Trigger

The issue of triggering has been delicate for LEP experiments, specially for what concerns $\gamma^* - \gamma^*$ physics which does not allow simple selections. The same is true in the case of SUSY "degenerate" scenarios (e.g. stop mass close to LSP mass) for which there would be a low energy release. The good news at this workshop is that "there is no trigger at a LC" ! Computing capabilities are such that we can perfectly hope for a complete registration of our events, with some mild zero suppression to keep the data volume reasonable, and a full asynchronous treatment of our events between bunch trains which would allow well controlled selections.

The Forward Region

I would like to give a major emphasis to this topic since at future LC forward detection will play a major role. This is clear for WW, ZZ and e^+e^- processes

which give very high rates. Tracking and calorimetry should therefore go down to the mask angle, that is ~ 100 mrad. Since the muon detector extends at a larger distance, muon can even be recovered below this angle.

One may worry about the precision on momentum which could be achieved at such angles but in a nice study performed with the S scheme, it has been shown [40] that a set of vertical Si wheels extending to ± 150 cm along the beam line, allow to preserve momentum resolution down to the mask angles (i.e. to better than 10% up to 250 GeV). In the L scheme a similar set up seems feasible (to be checked) provided that the inner radius of the gas detector starts at ~ 30 cm. One could then install a set of such wheels and presumably also have a vertical device behind the end plate of the TPC to give a precise measurement for energetic tracks (recall however that there should be a very small gap between the end-plate and the electro-magnetic calorimeter to avoid degradation of the electro-magnetic energy measurement).

The virtue of this forward coverage is obviously to reach an almost perfect acceptance ($>99\%$). This will be welcome for multijet events for which acceptance effects go like the power n of the solid angle. Systematics due to acceptance corrections will also be very low. One may imagine to re-measure at the Z pole the ratio R (hadronic rate/ $\mu^+\mu^-$) which provides a precise determination of α_s . Experimental errors, dominated by the uncertainty on acceptance corrections, would be very much reduced as compared to LEP.

Another major virtue of this almost perfect geometry is to reduce backgrounds induced by the WW process. If an electron or a muon from a semileptonic decay is lost, the hadronic decay will look as a SUSY candidate. One could argue that mass and energy reconstruction will identify an elastic W but this is only true on average with tails coming from beamstrahlung and from the W Breit-Wigner distribution.

The very forward region also deserves special attention. I have already given an example for "neutrino counting" techniques showing that our ability to veto on very forward electrons is essential to improve the sensitivity of this method. One can also emphasize SUSY searches which are limited in the "degenerate scenarios" when the mass of the particle comes close to the mass of the LSP. As an example, if one cannot veto electrons below 50 mrad at $\sqrt{s}=1$ TeV, these searches will be limited by $\gamma^* - \gamma^*$ backgrounds for mass differences ~ 25 GeV. At present one is contemplating the possibility to equip the masks with some active devices and to have a luminosity monitor inside the mask which goes down to 25 mrad. These devices can serve as vetoes against dangerous $\gamma^* - \gamma^*$ backgrounds, bearing in mind that most of the beam-beam induced background is built of soft particles easy to discriminate. The only potential problem comes from off-momentum electrons which, if too frequent, could generate accidental vetoes at an intolerable rate. Present estimates are that this rate will be reasonable if vacuum can be controlled as expected and that only a small fraction of these off-momentum electrons would end their life in the masking system. More "aggressive" goals, with a veto angle down to 5 mrad are also discussed.

The Tools

Due to lack of time I have been unable to review the tools for physics analyses. I would like however to make a few short comments on that important topic.

The issue of generators deserves special care since for channels with very high cross-sections like WW , e^+e^- and $\nu\bar{\nu}\gamma$, we could be limited by systematics. From LEP2 we have learned that some items were missing in standard generators and that the time scale needed to reach a satisfactory situation was longer than anticipated. Let me give you a few examples. In the GMSB searches we had to simulate the background producing 2 photons at wide angle and with large missing mass. An obvious contribution comes from radiative return to the Z pole, with Z decaying into $\nu\bar{\nu}$. 2 photon radiation, available, was insufficient since it left us with a recoil masses peaking at the Z mass, in disagreement with observations. It is fair to say that no one had asked for 3 hard photon emission during the LEP2 workshop. $\gamma^* - \gamma^*$ backgrounds, with VDM/QCD/QPM components, are necessary ingredients for our SUSY searches which have been rather difficult to control since, for good reasons, they do not motivate the specialists. The QCD sector, where one needs a good modelling of multijets, is still not completely satisfactory probably for the same reasons. No one is to blame but we need to get better organized for the next round.

For what concerns simulation and analysis tools, we are clearly still in infancy and we will benefit from the achievements (and mistakes !) from Babar and LHC. We should think early on how to keep user friendliness such that a large public, including our colleagues theorist, can participate to the preparation of our analyses. I think that this is an essential aspect which has been neglected up to now in these big battles to define software products.

Conclusions

The case for a LC has to be defended not only on grounds of the clean environment and more precise measurements but there should be a thorough comparison with the LHC potential for physics.

The light Higgs scenario is providing the strongest argument and this has to be consolidated by further progress both theoretical and experimental. Generally speaking, whether there is or not a light elementary Higgs, it seems very probable that the mystery of the EWSB mechanism can be clarified by a TeV LC.

The comparison between a TeV LC and LHC on SUSY and precision measurements has to be updated with the right hypotheses on detector, luminosity and maximal energy.

The issue of polarisation, i.e. which amount of polarisation, how precisely

known and how it is used, deserves clarification and detailed work.

For the detector/machine aspect, one should decide on the following items:

- can we achieve a VD accuracy $\sim 5\mu\text{m}+5\mu\text{m-GeV}$ with the Large option ?
- can we achieve, at reasonable cost, a fine-grained calorimeter in the Large option and what do we gain on physics ?
- down to which angle do we measure (or veto) charged particles, μ , e , γ ?

Sitges has given the 3 communities interested in future LC wonderful opportunities to exchange ideas and start discussions on a wide spectrum of topics. Since large meetings like this one cannot be too frequent, we should become a world-wide community by continuous communication between individuals sharing the same interest.

As nicely stated by Michael Peskin in the U.S. meeting, we have a task of "evangelism", that is we have to convince our colleagues involved in present collider experiments to join the LC world. Clear physics arguments are therefore needed to enlarge the present community and to convince our funding authorities.

There will be 3 projects of TeV collider proposed, corresponding to the 3 regional centers. We should help in reaching a rational issue to this healthy competition by stating clearly that we think that there should only be one world machine and that we all intend to work on it.

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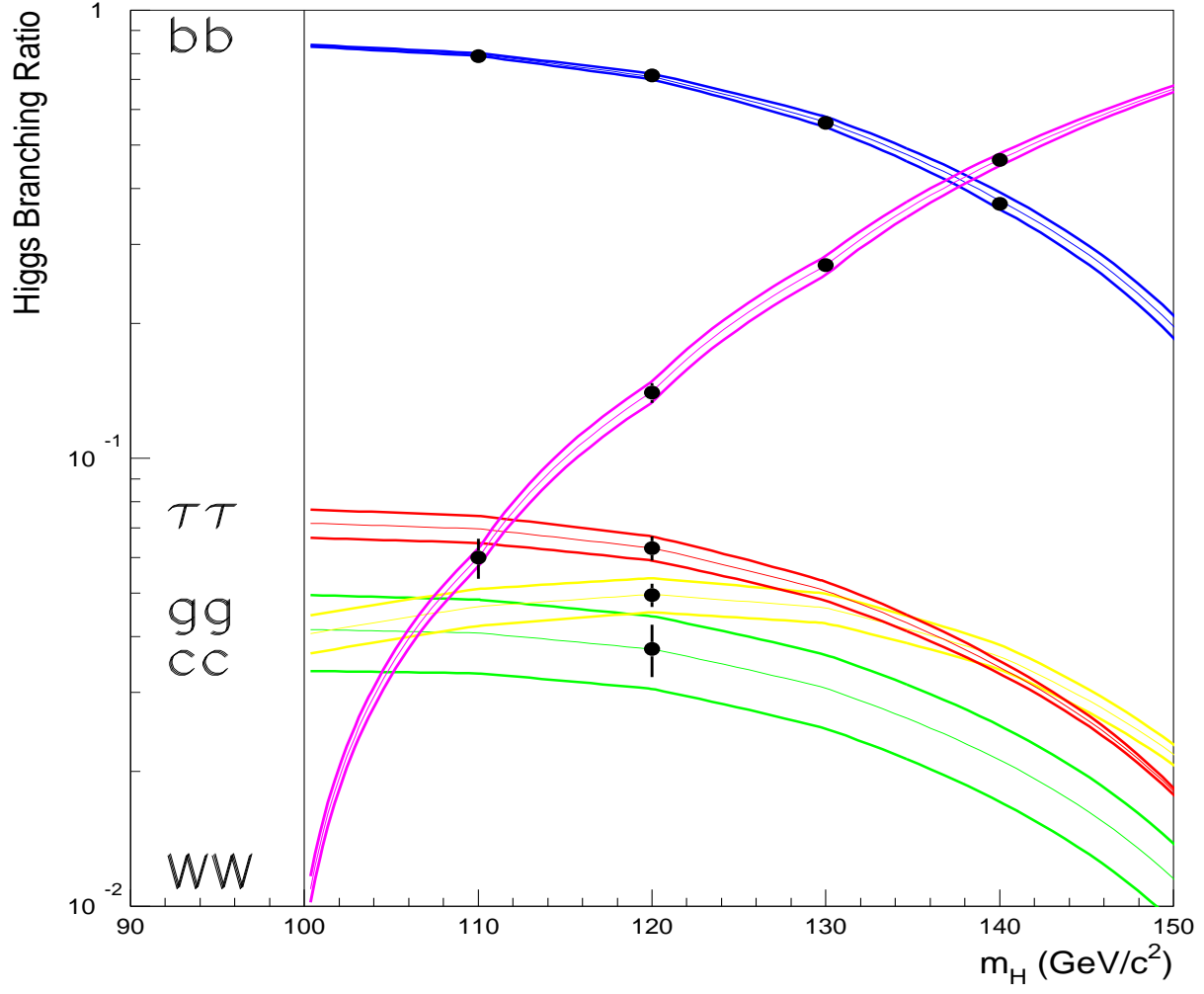


Figure 1: Expected precisions on Higgs branching ratios from a LC running at 350 GeV with 500 fb⁻¹ versus the Higgs mass. The dispersion of the curves indicates the theoretical uncertainties.

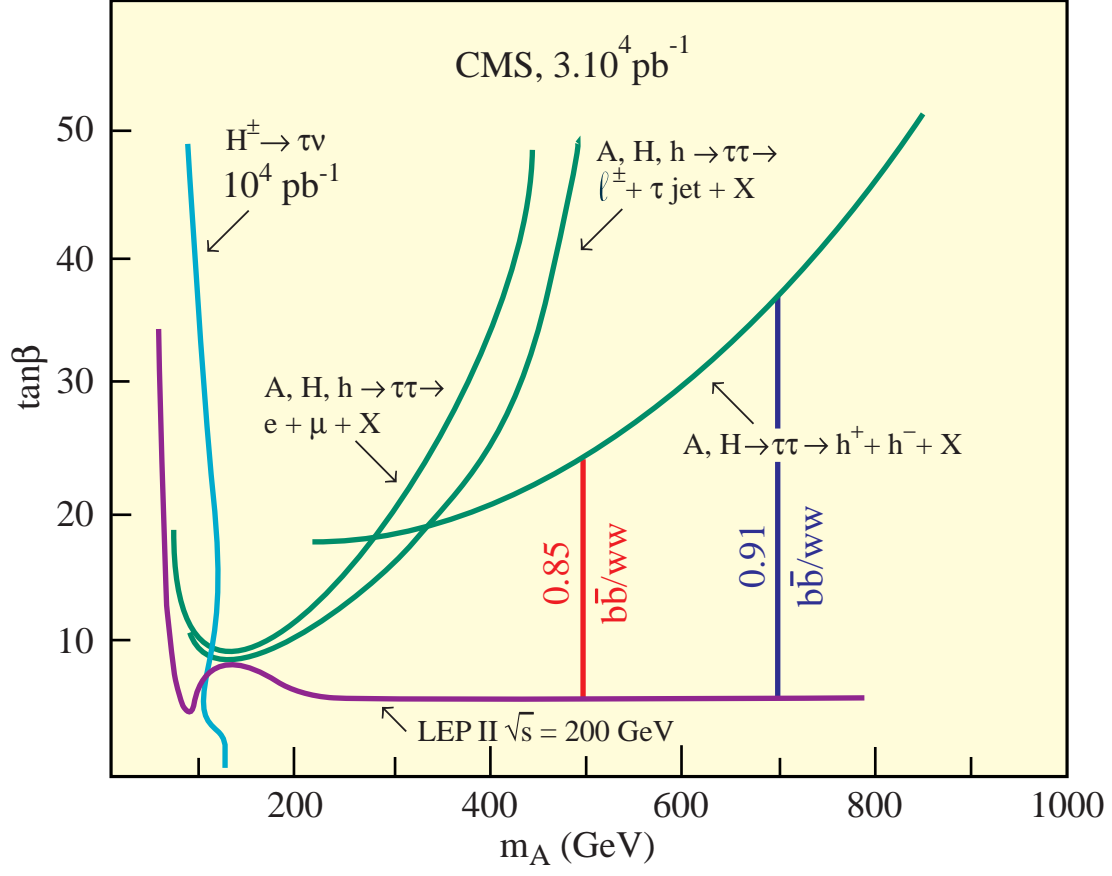


Figure 2: The curves indicate the expected coverage[11] of CMS+LEP2 in the $\tan\beta$ m_A plane while the 2 straight lines give the ratio MSSM/SM of $\text{BR}(h \rightarrow WW^*)/\text{BR}(h \rightarrow b\bar{b})$ in a region not excluded by CMS+LEP2.

Reach versus integrated luminosity

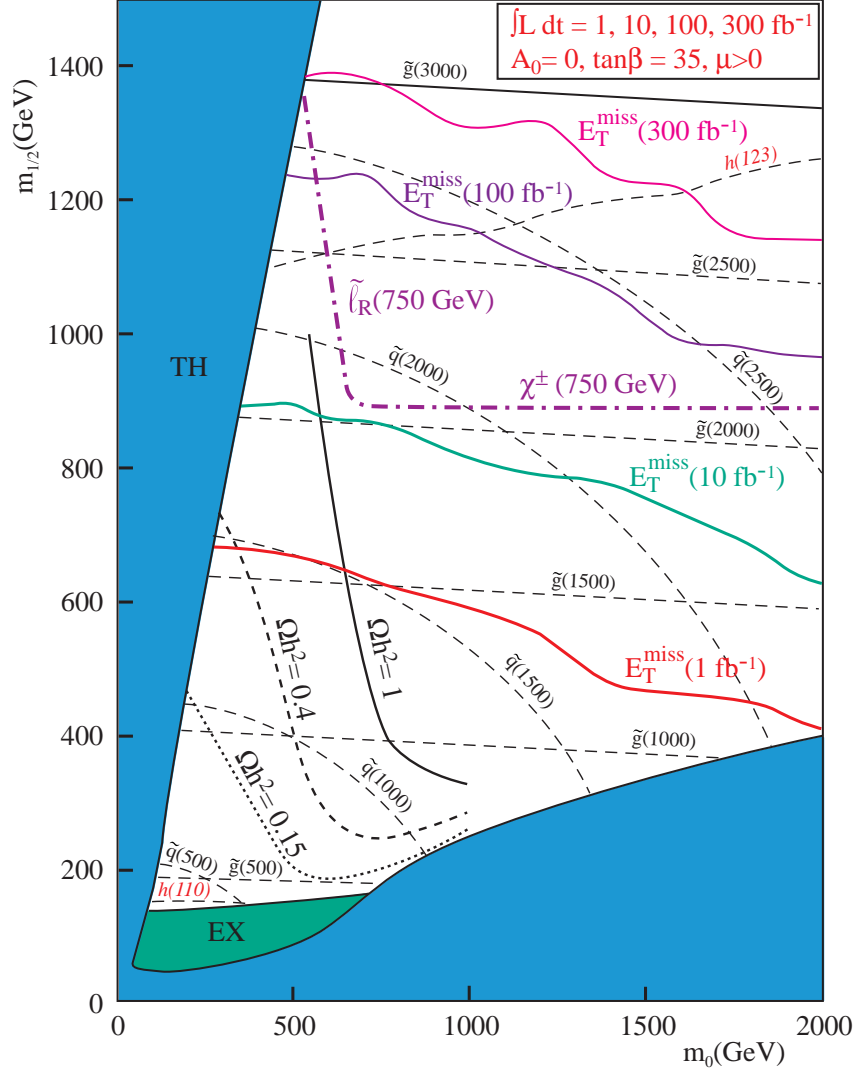


Figure 3: This figure[11] gives the discovery reach of CMS versus integrated luminosity in the MMSM-SUGRA scheme in terms of the gaugino $m_{1/2}$ and scalar m_0 masses adding up all missing energy channels. The dashed dotted lines are indicating the reach of a LC operating at $\sqrt{s}=1.5$ TeV for right-handed sleptons and for charginos.

Chargino / Neutralino study
 5σ significance contours at different luminosities

$$\sigma = N_{\tilde{\chi}_1^\pm \tilde{\chi}_2^0} / \sqrt{N_{\text{all}}}$$

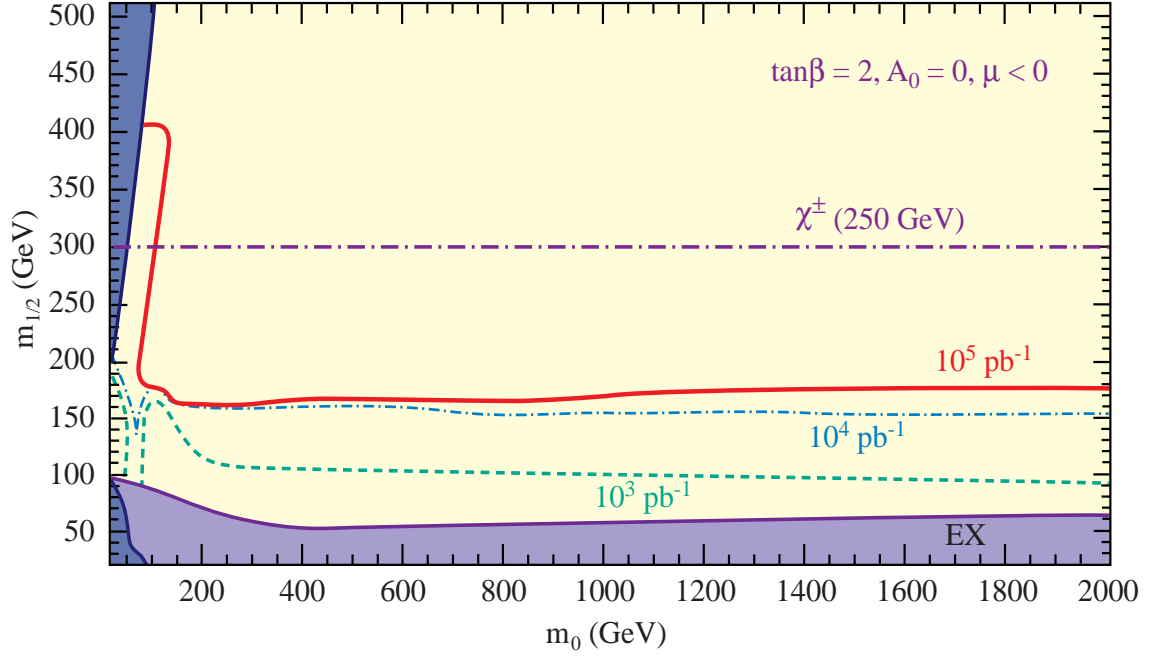


Figure 4: This figure[11] gives the discovery reach of CMS versus integrated luminosity in the MSM-SUGRA scheme in terms of the gaugino $m_{1/2}$ and scalar m_0 masses for the chargino/neutralino searches. The dashed dotted line indicates the reach of a LC operating at $\sqrt{s}=500$ GeV for charginos.

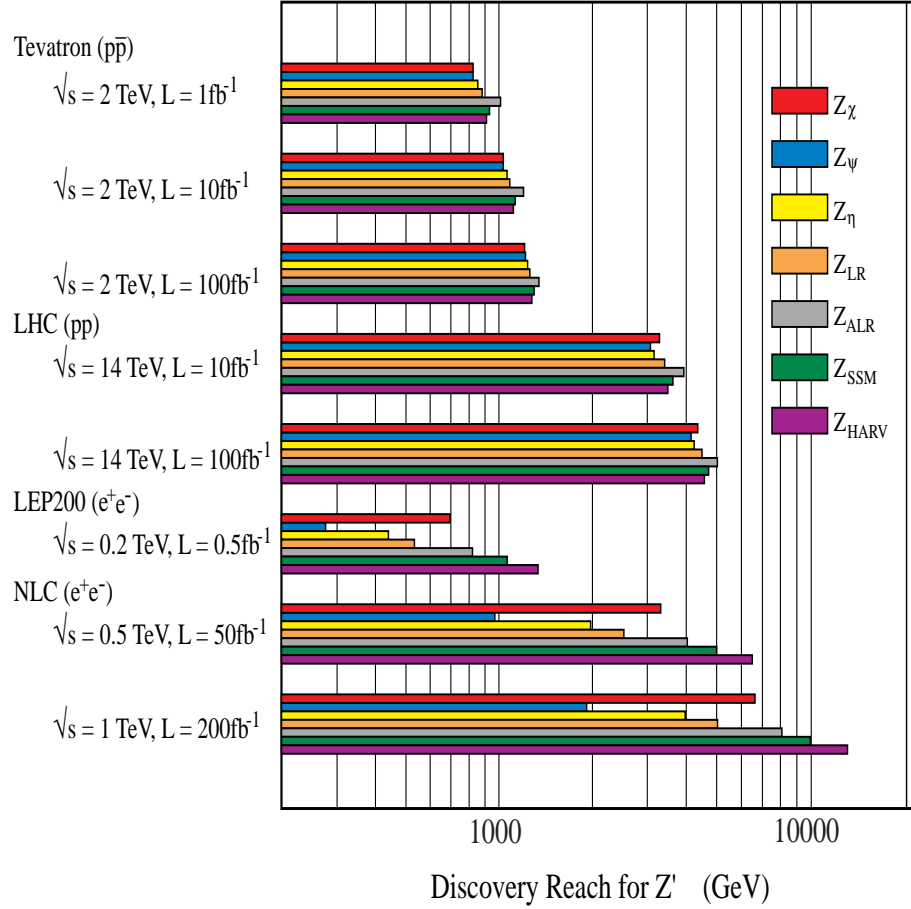


Figure 5: Discovery reach for Z' given by the various machines for the different scenarios.

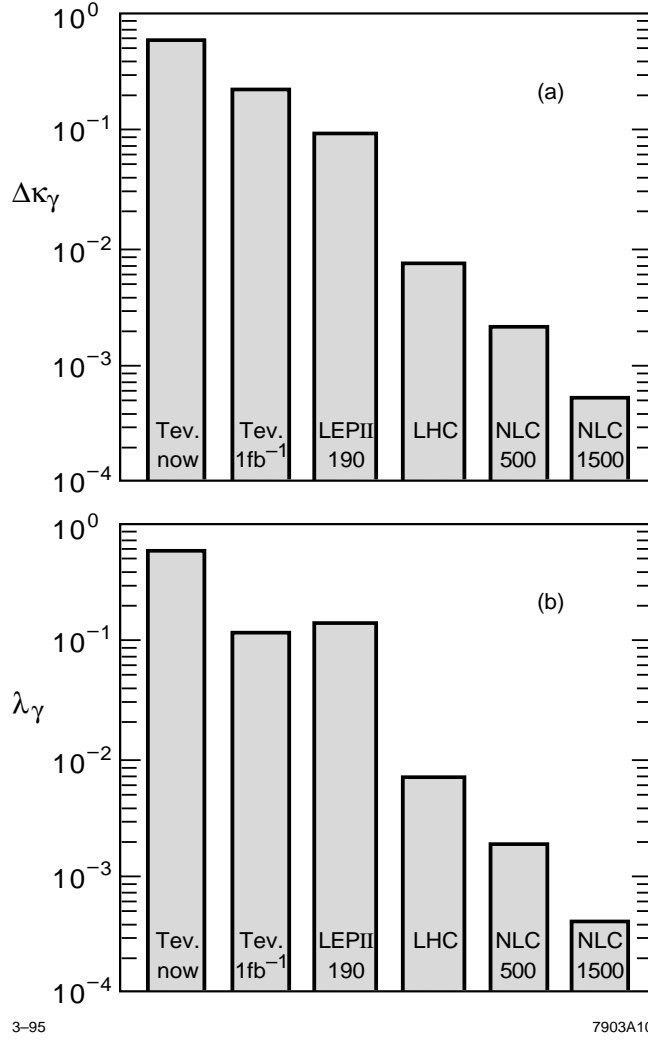


Figure 6: Precision on anomalous couplings of photons to W from Tevatron, LEP2 with 0.5 fb^{-1} , LHC, NLC with 100 fb^{-1} at 500 GeV and with 200 fb^{-1} at 1500 GeV.

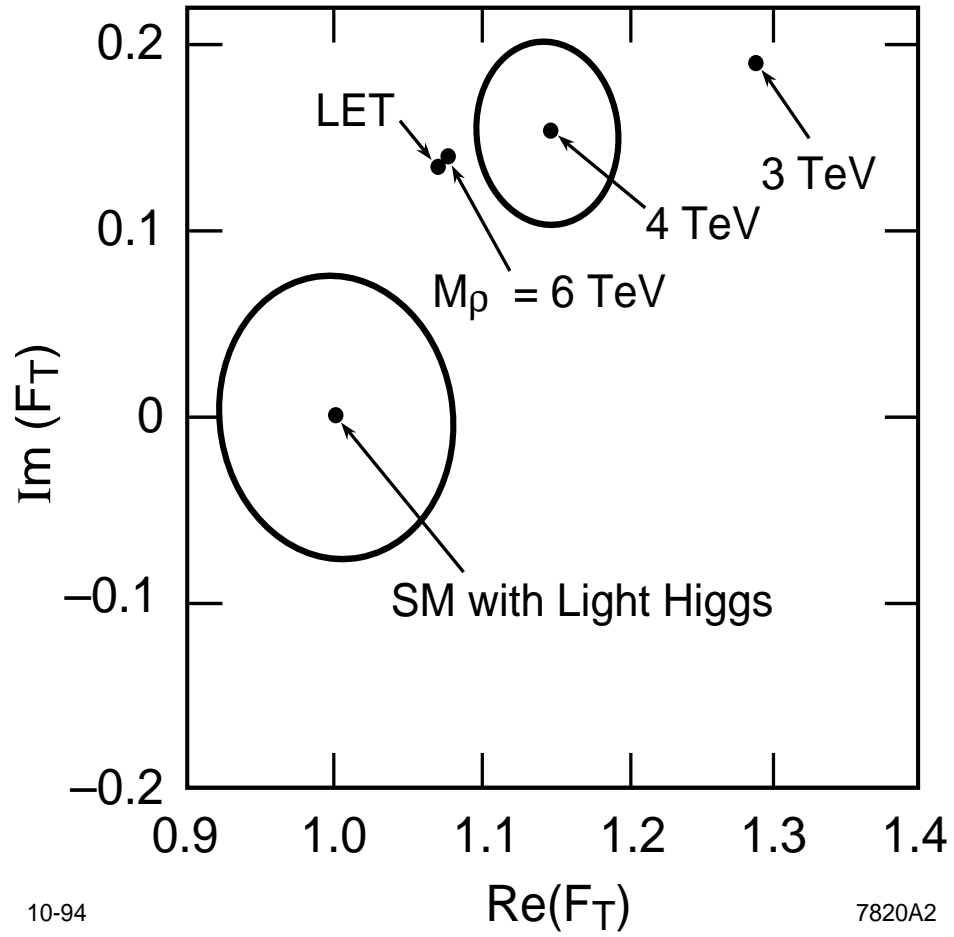


Figure 7: Deviations on $e^+e^- \rightarrow W^+W^-$ due to strong interactions when there is a ρ -type resonance sitting nearby with precisions (ellipses) given by an NLC at 1.5 TeV and with 200 fb^{-1} . The point labeled LET corresponds to the deviations without a resonance (low energy theorems).

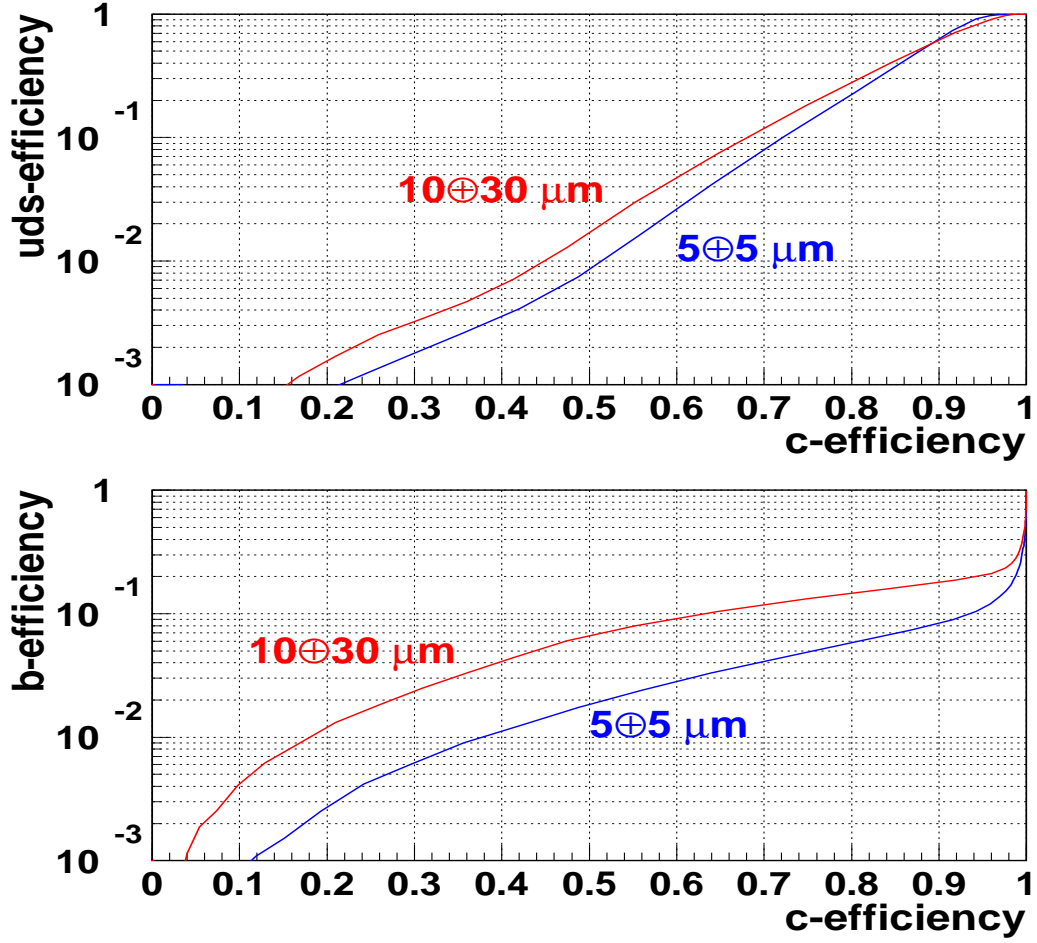
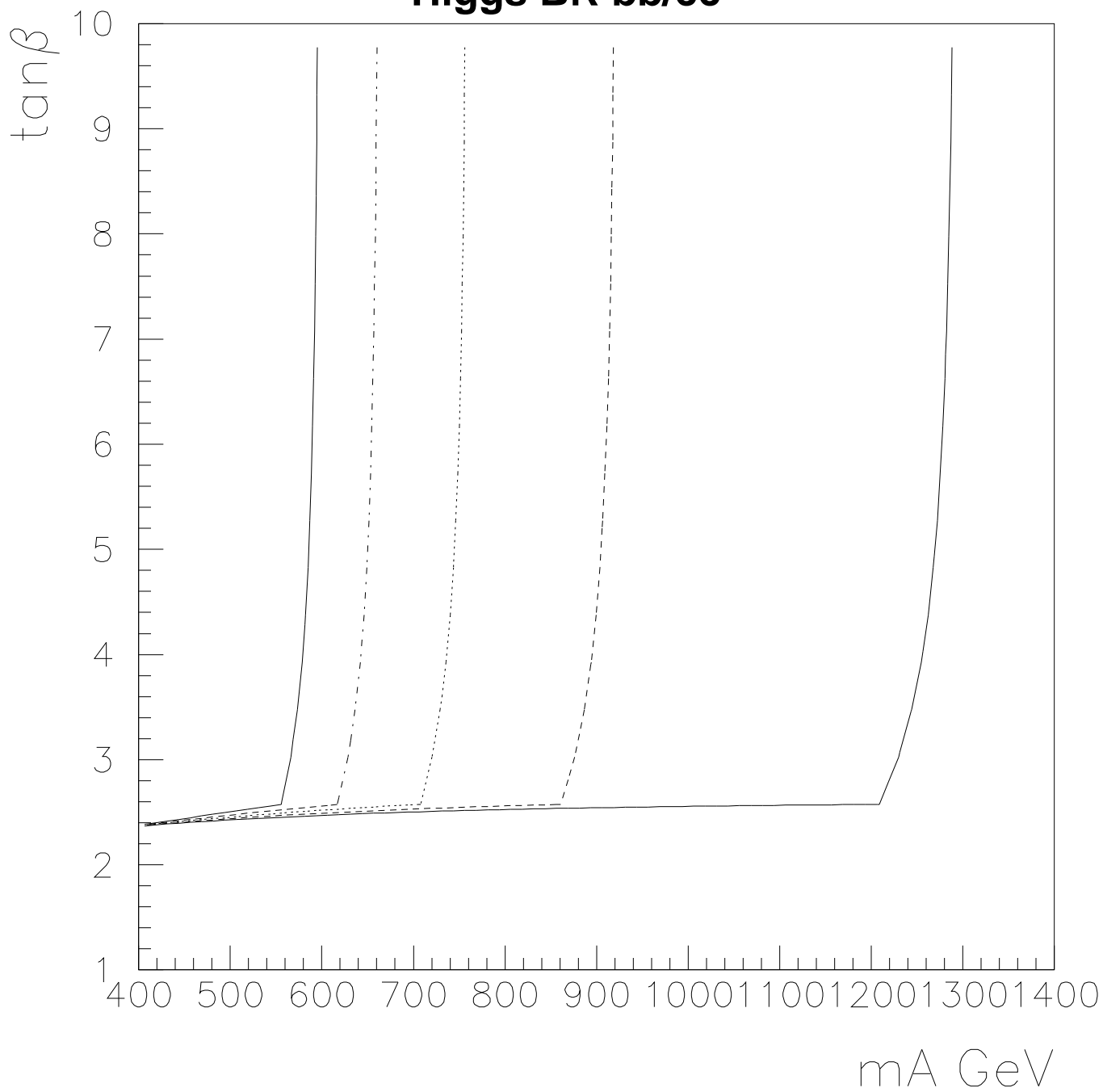


Figure 8: The upper plot illustrates the effect of impact parameter accuracy on light quark(or gluon)/c-quark separability. The lower plot gives the information concerning b-quark/c-quark separability.

Higgs BR bb/cc



Higgs BR bb/WW

